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DISTRIBUTED DECISION AND COMMUNICATION PROBLEMS IN TACTICAL USAF COMMAND AND CONTROL

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1. INTRODUCTION

The analysis of generic aspects of C^3 systems reprents an area of research that requires the integration of diverse concepts and theories, if progress is to be made toward the development of a theoretical basis of their analysis and design.

During the third year of this project, the technical effort continued to be directed toward generic, long range, basic, unclassified research. The emphasis was on general methodological and technical issues, but from the perspective of the unique needs and requirements of the Air Force. The four research areas specified in the statement of work were:

(a) C^3 System Structure and Organizational Forms

(b) Decentralized Estimation

(c) Information Storage and Flow in C^3 Systems

(d) Distributed Decision Problems in Dynamic Missile Reassignment Strategies.

Progress was achieved in each of these areas, as summarized in the next section. The last three were brought to conclusion during this past year; while the first one is continuing along several new directions. The list of documents resulting from research carried under this project is included in Section 3. Section 4 contains a list of professional personnel that were supported by this contract.

2.0 STATUS OF RESEARCH EFFORT

2.1 C^3 System Structure and Organizational Forms

(Dr. Alexander H. Levis, Ms. S. A. Hall, Mr. K. L. Boettcher, and Ms. G. Chyen)

Research in this area has been focused on the development of a mathematical theory for the modeling and analysis of information-processing and decisionmaking organizations. The specific organizational structures considered were motivated by tactical Air Force C^3 systems, perceived as support systems for the decisionmakers.

The first problem addressed was the development of a model of the decisionmaking process applicable to human decisionmaking in tactical situations. A model was developed using the analytical framework of n-dimensional information theory. The interactions with other decisionmakers were modeled in terms of sharing situation assessment information and issuing or receiving commands that restrict the selection of outputs or responses.

The theory developed for the single interacting decisionmaker was then extended to teams of decisionmakers forming an organization. There are three parts to the formultion of the design problem: (a) analytic characterization of the task the organization is to perform, (b) Specification of the interactions between organization members and the environment, i.e., who receives what external inputs and who produces the organization's outputs, and (c) Specification of the interactions between organization members. These include the sharing of situation assessment information and the issuing and receiving of commands.

The theory in its current form is applicable to organizations with acyclical information structures, i.e., organizations whose digraphs depicting information flow do not contain loops. The conventional workload-performance plane for the single decisionmaker has been extended to n+1 dimensions with the n dimensions corresponding to the workload of each one of the n membersof the organization and the (n+1)st dimension to the performance

measure for the organization. The theoretical development has been illustrated by designing and evaluating two three-person organizations assigned to carry an abstracted air defense task.

In the work described thus far, the internal structure of the decisionmaking systems has been modeled as memoryless. In order to develop more realistic models in the context of the command and control process, it became necessary to introduce memory so that inputs that are statistically dependent may be considered. The objective of this reearch task, therefore, was to develop analytical models of different types of data storage using the information theoretic framework.

Three types of storage have been modeled: buffer storage, temporary storage (short term memory), and permanent memory (long term memory). Since this analysis addresses the processing of sequential inputs that are dependent on each other, information rates and the partition laws for information rates are used. Consequently, inputs are modeled by discrete stationary ergodic sources. The model of permanent memory was then used to analyze a typical situation for a decisionmaker: the processing of two distinct tasks in parallel — the dual task problem.

The current model of the decisionmaking process contains a set of algorithms in the situation assessment stage and another set in the response selection stage. The simplifying assumption was made that the algorithms were deterministic. The theory has been extended to include stochastic algorithms.

First, information theoretic models of stochastic algorithms were developed. Then, these models were incorporated in the model of the interactive decisionmaker and the total activity was evaluated. As expected, it was shown that the presence of non-deterministic algorithms increases the total activity by increasing the component of total activity the corresponds to internally generated information or noise.

More recent work has been focused on the modeling of preprocessors of

various types. The objective is to develop an analytical formulation of the problem of introducing decision aids in an organization. Both deterministic and stochastic preprocessors are being studied and their effect on workload and performance is being investigated.

Finally, an effort has started to develop a set of programs that can be implemented on a microcomputer (e.g., the Northstar Advantage) that can be used to compute the workload-performance loci of alternative organizational forms. A detailed flowchart has been developed and the basic specifications of the program's modules have been outlined.

2.2 Decentralized Estimation

(Dr. D. A. Castanon)

This task was completed during the previous reporting period and a technical paper was prepared. The paper received minor revisions and improvements during the current reporting period. It has now been accepted for publication in the journal Large Scale Systems.

2.3 Information Storage and Flow in C^3 Systems

(Ms. E. R. Ducot)

During the previous reporting period, this task was completed and a report describing the TECCNET system was prepared. This interactive facility is currently available at the Multics computer system at M.I.T. It will be maintained for use by researchers studying the interactions between the various data and network management strategies and the behavior of the network as seen by the information user.

2.4 Distributed Decision Problems in Dymanic Missile Reassignemt Strategies

(Professor Michael Athans and Mr. Y. L. Chow)

Research continued for a class of generic air defense problems involving the dynamic stochastic assignment of N defense interceptors against M incoming enemy targets. Key constraints are generated by the assumption that an illuminating radar must reflect energy from each target for a specific amount of time so that the interceptor guidance law can lock on the target.

The modeling phase of this research has been completed. Equations have been derived that relate one-on-one kill probabilities and other system variables to the overall probability of destroying all incoming targets. Two stochastic strategies were developed: the shoot-look-launch strategy and the shoot-look-reassign strategy (these include the flexibility of lauching a salvo of interceptors against a target possibly followed by another salvo after kill assessment). Numerical results for optimal stochastic dynamic strategies for simple scenarios were obtained.

The analytical results have demonstrated that to solve successfully this class of dynamic optimization problems one needs significant modifications of the available stochastic dynamic programming theory and algorithm.

Long range research directions include the formulation and solution of the distributed version of the above problem. This represents challenging and relevant theoretical research.

3. PUBLICATIONS

3.1 Journal Articles

(a) K. L. Boettcher and A. H. Levis, "Modeling the Interacting Decisionmaker with Bounded Rationality," IEEE Trans. on Systems, Man, and Cybernetics, SMC-12, No. 3, May/June 1982.

(b) A. H. Levis and K. L. Boettcher, "Decisionmaking Organizations with Acyclical Information Structures," IEEE Trans. on Systems, Man and Cybernetics, SMC-13, No. 3, May/June 1983.

(c) K. L. Boettcher and A. H. Levis, "Modeling and Analysis of Teams of Interacting Decisionmakers with Bounded Rationality," Automatica, Vol. 19, No. 6, November 1983.

(d) D. A. Castanon, "Decentralized Estimation of Linear Gaussian Systems," to appear in Large Scale Systems, North-Holland Publishing Co.

(e) M. Athans, "The Expert Team of Experts Approach to Command and Control (C^2) Organizations, IEEE Control Systems Magazine, Vol. 2, No. 3, Sept. 1982, pp. 30-38.

3.2 Refereed Conference Proceedings

(a) K. L. Boettcher and A. H. Levis, "Modeling the Interacting Decisionmaker with Bounded Rationality," in

Proc. 4th MIT/ONR Workshop on C^3 Systems, LIDS-R-1159, Vol. IV, MIT, Cambridge, MA, October 1981.

Control Systems Theory and its Application, Proc. Bilateral Seminar on Control Systems, Science Press, Beijing, PRC, April 1982.

(b) A. H. Levis and K. L. Boettcher, "Decisionmaking Organizations with Acyclical Information Structures," in

Proc. 5th MIT/ONR Workshop on C^3 Systems, LIDS-R-1267, MIT, Cambridge, MA, December 1982.

Proc. 21st IEEE Conference on Decision and Control, Orlando, FL, December 1982.

(c) A. H. Levis and K. L. Boettcher, "On the Design of Information Processing and Decisionmaking Organizations," in Optimization of Systems, J. Lions and A. Bensoussan, Eds., Springer Verlag, Berlin, FRG,

December 1982.

3.3 Graduate Theses

(a) K. L. Boettcher, "An Information Theoretic Model of the Decision Maker," S.M. Thesis, LIDS-TH-1096, MIT, Cambridge, MA, June 1981.

(b) D. A. Stabile, "The Design of Information Structures: Basic Allocation Strategies for Organizations," S.M. Thesis, LIDS-TH-1098, MIT, Cambridge, MA, June 1981.

(c) S. A. Hall, "Information Theoretic Models of Storage and Memory," S.M. Thesis, LIDS-TH-1232, MIT, Cambridge, MA, August 1982.

(d) G. Chyen, "Information Theoretic Models of Preprocessors," S.M. Thesis, in preparation.

(e) Y. L. Chow, "Dynamic Missile Reassignment Strategies," S.M. Thesis, Dept. of EECS, MIT (draft available; final draft in preparation).

3.4 Technical Papers and Reports

(a) D. A. Stabile, A. H. Levis, and S. A. Hall, "Information Structures for Single-Echelon Organizations," LIDS-P-1180, MIT, Cambridge, MA, January 1982.

(b) E. R. Ducot, "TECCNET: A Testbed for Evaluating Command and Control Networks," Report LIDS-R-1227, Laboratory for Information and Decision Systems, MIT, Cambridge, MA August 1982.

(c) S. A. Hall and A. H. Levis, "Information Theoretic Models of Memory in Human Decisionmaking Models," LIDS-P-1300, MIT, Cambridge, MA, June 1983.

4. PERSONNEL

Dr. Alexander H. Levis, Co-Principal Investigator

Professor Michael Athans, Co-Principal Investigator

Ms. Elizabeth R. Ducot, Research Staff

Mr. Kevin L. Boettcher, Research Assistant, Ph.D. candidate

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Ms. Gloria Chyen, Research Assistant, M. S. degree candidate

Mr. Y. L. Chow, M. S. degree candidate

Ms. Elizabeth Hinzelman, M. S. degree candidate